"RELATIVITY."

A SEARCHLIGHT ON HUMAN PERCEPTION.

MODERN science and philosophy reveal with increasing emphasis that we superimpose our human qualities on external nature to such an extent that it has been seriously asked whether matter has any real or "absolute" existence outside of our mind. Many of us have sought comfort in the thought that we possess geometrical axioms and mechanical laws that were as untainted by human-sense perceptions as mathematics. Intellects on other inhabited worlds should find them as immutable as we. Albert Einstein has taken our last stronghold. Fortunately he is not only a destroyer but an upbuilder as well. Into dissent he brings harmony, if mechanics based on one hypothesis is more harmonious than when built upon many. Beyond an hypothetical world explanation we cannot hope to arrive.

We call our new hypothesis "The Theory of Relativity" because we can prove that no two observers can describe a physical happening in the same terms if they are moving relatively to each other; that their measurements of size, weight, velocity, direction of travel, of the object under observation will differ; and further that there exist no means of determining whose measurements are true or "real." Both sets of determinations are of equal value. The greater the relative motion of the two observers, the more will their measurements disagree.

This is very bewildering; is there then no reality, no standard, no "truth" upon which we can build our conception of the universe? Let us reassure ourselves; the relativist as much as the orthodox scientist deals with absolute quantities and it is our object presently to make their acquaintance, only his realities bear a similar relation to our perceptions as various frequencies of light waves bear to pigments. Our slowly through the ages developing senses are not yet able, and probably never shall be able, to grasp objects or occurrences in all their aspects or in their full extension; in particular they do not take sufficiently into account that *time* enters in a very intimate manner into all observations. We must try to grasp that all matter has extension in time as well as in space; that it is not sufficient to locate an object two squares ahead, three to the right, ten stories up, *i.e.* along three space axes, but we must also specify the point along our "time-axis" when the observation is made, if we are to correlate the object in question with anything else in the world. In the "absolute" world which we must picture to ourselves, "objects" must be replaced with "events" because when my eye measures the length, width and breadth of an object these measurements consist of a series of events radiating from the object and experienced by my eye in a string of happenings lined up in time and, similarly, any and everything that happens to, in and around the object takes time, and is strong out in time, so that its "real" existence cannot be described without adding time as a "fourth dimension." It is here our imagination balks, but it is just when we have formed an understanding of the statement that time enters into our world picture very nearly in the same manner as length, breadth and height that we also shall understand which measurements have absolute value, why the measurements of the two observers disagree, why gravity acts equally on lead and feathers, and

many other puzzles of science and, lastly, we shall obtain a glimpse of a universe which while without beginning or end, without bottom or top, yet is finite, but without boundaries.

Such a glimpse is worth our while; therefore let us struggle on with our time-dimension or fourth dimension.

As the difficulty we experience, when trying to picture time to ourselves as a fourth dimension, depends on the inadequate development of our senses, we must *intuitively* extend our vision and can most easily do so by first entering into the world of such beings who as yet lack the sense perception of one of our three space dimensions and examine the place time occupies in their universe.

Consider for instance the world of the dog. Our time does not exist to him. He has no concept of yesterday or tomorrow; he lives in a continuous now. *What then constitutes time to the dog?* His behavior indicates that while he has learned to *act as if* there were depth in the picture before him, he cannot conceive distance between two objects lying on one line ahead of him. Therefore when the dog runs along the road the surrounding world becomes a moving picture: the distant trees stand still and the fence posts rush them by. The post opposite his eye belongs to his present, the previous post to his past and the following post to his future. This is precisely the way our time comes in contact with our senses. Our third dimension therefore is *time* to the dog. The past fence post and the coming fence post belong as much to "history" in the dog's life as the past and the coming year are part of our history. The dog sees motion in the landscape before him where we see nothing but stationary objects because we conceive three instead of two dimensions. The dog may run in a straight line and he sees the objects near him in a uniform rectilinear motion; he runs around the corner of the house and the *house revolves.* These motions in the

time of the dog are natural to him; they do not evoke his apprehension. But let something move in our three dimensional sense and it becomes *alive* to the animal whether it be a motor car, a spinning wheel or the cat's own tail. Here is life, mystery and perhaps danger. The blind is an entirely useless adjunct to the duck hunt provided the hunter could keep motionless; strange forms do not frighten the animal, they only arouse its curiosity; but let the hunter move only a finger, sometimes only an eye, and life, that is possible danger, is there. If we now understand what time is to the dog and remember that it "runs across the face of the dog," that is *at right angle* to his space, then we may by analogy understand the real meaning of time in our own three dimensional world. Past, present and future represent motion in the fourth dimension, and this fourth dimension or time axis is at right angle to our space. Furthermore, "the past" to one dog is evidently "the future" to a dog running in the opposite direction, and similarly past and future is a relative conception in our time also and depending on our state of motion. It must be remembered, however, that there is an irrevocable past and an impenetrable future in our time which has no analogy in space. But physical measurements deal with time in a zone, analogous to the landscape in front of the dog, where past and future are purely relative and may even be reversed between two observers.

The table below gives a picture of the evolution of space and time perceptions parallel to the evolution of life.[1]

NO. OF DIMENSIONS	1	2	3	4	5
One dimensional sense-perceptions: Snail	Width	Motion in time	Life Mystery		
Two dimensional sense-perceptions: Dog	Width	Height	Motion in time	Life Mystery	
Three dimensional sense-perceptions: Man	Width	Height	Depth	Motion in time	Life Mystery

[1] P. D. Ouspensky's book *Tertium Organum*.

We must therefore admit that time shares in most of the qualities of space and that all objects, or more correctly, all events (for the substance of matter *is* motion) have extension in four dimensions.

A bridge between orthodox space and time on one hand, and the four-dimensional world on the other, is formed by the fact that light travels 186,000 miles per second and that this velocity can be determined "absolutely," *i.e.* without the uncertainty (apart from errors of observation) that impairs all measurements of smaller velocities, so that we can speak indiscriminately of seconds and miles in our four-dimensional world. To this new world we have given the name: *Space-time.*

Let us now consider why human observations differ from each other when projected into the components of space-time, *i.e.* when made in space and time separately. In our analogy from the world of the dog it is easy to see that his "time" changes direction, as the direction of travel of the dog changes, but for the more exact understanding of the phenonemon we may take an example from our three-dimensional world.

An observer on board a ship in harbor and an observer on shore agree as to the length, width and height of the ship. When, however, the ship steers out on the ocean the ship is gradually tilted with reference to the observer on shore due to the curvature of the earth so that the ship apparently loses in height even if our observer on shore always could see the whole ship. The line that is vertical to him forms a larger and larger angle with the vertical on board so that vertical is partly transformed into horizontal and vice-versa. Although vertical appears very distinct from horizontal to the observer on shore the identical direction has no specific meaning on board the boat at sea. Space is entirely indifferent to the location of our main three axes of reference in space, in other words, it is isotropic. Four

dimensional space-time is quasi-isotropic. It certainly pays no attention to the directions in which different observers count time. To any particular object, at some particular point in space-time, its experiences, which is the stuff it is made of, are strung out in a very distinct time order. But viewed from another object, which moves with reference to the first, the time axis as well as the three space axes are tilted so that time is transformed to space-dimensions and vice versa. There is therefore no absolute differentiation between time direction and space direction any more than between horizontal and vertical in our ship analogy. Space-time is in truth a four-dimensional continuum not a three-dimensional space with time in some manner superimposed. *When time direction as well as space directions are viewed under oblique angles their divisions, say in unit lengths, naturally change size like the height of the tilted ship.* We can already now explain one of the beforementioned puzzles of science. Two famous experiments, performed with great accuracy, seemed to indicate, one that the aether is not carried along with moving bodies but passes or "blows" freely through the interstices of matter. The other proved just the reverse. To account for this baffling result many ingenious theories were offered, the most plausible of which was that all matter in motion suffers a contraction in the direction of its motion and the amount of this contraction was arbitrarily chosen so as to account for the discrepancy. The relativist who believes in four-dimensional space-time calculates the contraction due to the tilting of the axes involved in the experiments and finds that the contraction necessarily must have the value which reconciles the experiments.

It is interesting to note just how large the contraction of the earth must be if viewed from the sun. The theory gives a contraction in the ratio $\sqrt{1-(V^2/C^2)}$ where "C" is the velocity of light and "V" the velocity of the object rela-

tive to the observer. Inserting values for the velocities of light and of the earth relative to the sun, we find a contraction of two and one-half inches on the diameter of the earth. This is a fair example of the magnitude of the corrections that the theory of relativity imposes on the prevalent laws of mechanics and yet what a revolution of thought it introduces.

If we examine the expression $\sqrt{1\ (V^2/C^2)}$ we notice that if "V" equals "C" the whole term becomes zero, in other words an object passing the observer with the velocity of light would appear to have no length, it would have shrunk to a surface. In reality this could not happen because it would take an infinite force to impart light velocity to a particle of matter. This velocity is therefore the highest possible velocity in the universe, that man at present can conceive, and it is furthermore, or rather therefore, "absolute," *i.e.* all observers agree on its value, if measured in vacuum and sufficiently far from gravitational influences.

But are these changes in time and space "real"? A futile question. We cannot say that any point of observation in the universe has preference over any other because we do not know the absolute motion of any point. If we had found an inflexible, unyielding aether-wind blowing through space and matter we might have assumed the aether as standing still and chosen units of time and space measured along reference axes drawn in the aether as our absolute standards. We might then perhaps have permanently separated space and time. As the aether is superflous in the world of relativity, the relativist is indifferent as to whether the aether hypothesis is retained or not.

But we face again the question: how can we describe nature if all our measurements are relative, dimensions and duration depending on the motion of the observer? So far we have only found the velocity of light to be "absolute" under certain conditions. If, however, we follow an object

along its *worldline, i.e.* along its track through space-time, we should be able to make a record of the "distance" we travel, each unit measure along the wordline advancing in both time and space, and make notations of the place and moment at which our track crosses other worldlines, that is note the time and place of all the events that constitute our experience. The time thus noted is called the "proper time" for the worldline followed. The "distance" between two events is called an *interval* and here we meet again an absolutee quantity independent of the point of observation. We share in the motion of all objects on earth to such an extent that the necessity for measuring intervals instead of length and time separately does not occur in our practical life until we commence to explore the stellar spaces or observe particles moving with velocities approaching that of light as for instance particles shot out by radio-active substances. In these macrocosmic and microcosmic worlds, however, we must measure intervals because we are unable to follow the observed objects in their own tracks and are obliged to use "local" space and time directions and we know now that such measurements have no direct application on the object moving relatively to us. The mathematician, however, is able to calculate the interval between two world-points on a worldline from "local" observations much as a surveyor calculates the distance between two mountain tops, that he cannot reach.

Intervals are absolute, *i.e.* the worldline in space-time form a net-work whose location in space-time is independent of the observer. The intervals from knot to knot, *i.e.* from event to event, are not straight. They would be straight for an object moving with uniform velocity in a straight line in three-dimensional space or which is the same, moving with uniform velocity in a space free from other matter. Such motions do not exist in nature. All motions within our experience are curved in three-dimensional space and

very frequently the velocity in the curved path is not uniform but accelerated or retarded. In any case their track in space-time is curved. The worldline of the earth is essentially a spiral, a loop in space pulled out in time to such an extent that the windings are hardly discernible when viewed at right angle to the path. We see a closed orbit only when looking along the time axis so that the windings are superimposed upon each other. In similar manner most worldlines approach straight lines. Why should they curve at all? The curvature in the orbits of the planets in space is, according to Newton, due to a mysterious force, gravitation. Of the nature of gravitation we know literally nothing except that it follows the mathematical law, formulated by Newton, and long considered the model of all natural laws. Newton's well-known law of gravitation states that two material bodies attract each other with a force directly proportional to their masses and inversely proportional to the square of their distance. The mass of a body, or the quantity of weighable matter it contains, has been considered an absolutely unchangeable constant. It has lately been found that this is not strictly true. Particles shot out by radio-active matter have been proved to possess a mass increasing with the square of their velocity. Their change of mass was measurable because their velocity approached that of light, 186,000 miles per second, while the speed of a rifle bullet is less than one mile per second and therefore the change of mass with velocity has entirely escaped our notice until the radio-active substances were discovered. This change of mass with velocity leads to the amazing conclusion, also supported by electro-magnetic theory, that *all mass is due to motion,* whether it be the motion apparent to our senses or the motion with which our intellect has filled the "interior" of matter. But "what" moves there? The "what" must

itself be motion, if it has mass, so that matter, if thought to mean substance, utterly vanishes before our mind.

We see therefore that when we speak of mass in Newton's law we do not accurately know what mass we are talking about. But neither are we able to say what the distance between the two moving stellar bodies is. For what point of observation shall we choose? Thus Newton's law has become ambiguous although the variations involved are of insignificant magnitude as long as we deal with ordinary velocities. It also leads to one of those puzzles of science that relativity delights to explain. The orbit of the planet Mercury is an ellipse the major axis or largest diameter of which should always remain parallel to itself in space according to Newtonian mechanics and except for deviations already known to science. Astronomers have, however, observed a slow turning of this axis amounting to about 42 seconds of arc per century which has no known cause. The accuracy of this observation is so great that the probable error could not be as much as two seconds. Although we have not yet seen in what manner the theory of relativity replaces Newton's law, we might state already now that it gives a value of 43 seconds per century to the turning motion mentioned, one of the most remarkable verifications of a theory in the history of science.

We cannot state our new law of gravitation until we have given a little further study to the quantity mass. We meet it not only in the problem of gravitation but whenever we start or stop, change the velocity or direction of a moving body. When the elevator starts upward we feel an increased pressure from the floor; when the train starts or stops we lurch backward or forward as if there was a magnet pulling us in a direction opposing our change of motion. When the elevator starts upward it is as if our mass or that of the earth had increased. But we know the phenomenon is the result of our acceleration only. And again we

might remove the earth altogether, *i.e.* abolish gravity in the elevator provided we increase our "upward" acceleration with 32 feet per second which is the change in velocity due to gravity. We would then be entirely ignorant of the removal of the earth as far as anything inside the elevator was concerned. In fact, all the phenomena due to an acceleration may be identically reproduced by introduction of a suitable mass *and in small regions the reverse is also true,* as in the case of the elevator. This is the *principle of equivalence* which plays such an important part in the theory of relativity. We see now that by studying acceleration we study gravitation as well. It is a remarkable fact that the entire theory of relativity is with logical necessity developed from the two postulates propounded by Einstein: 1. The constant velocity of light in vacuum. (Along its worldline light does not travel with constant velocity in the neighborhood of matter.) 2. The principle of equivalence.

Let us now look at gravitation and acceleration from the relativist's point of view. We shall first see that mass is relative just as length and time are, *i.e.* dependent on the motion of the observer. This follows directly from the fact that mass varies with velocity and time enters into any statement of velocity. The observer uses his "proper time," *i.e.* measures time along the direction of his "local" time-axis in space-time which is tilted with reference to the local time-axis at the worldline of the moving body and therefore he obtains local time and consequently also local mass. The theory of relativity gives exactly the change of mass with speed found in radioactivity. Again we need not despair less the absolute has disappeared, for mass multiplied with time, which we call action, is absolute, *i.e.* independent of the observer, and gives us therefore an exact basis for our calculations.

In Einstein's law of gravitation "local' 'mass and "local" space-measures replace the "absolute" quantities in New-

ton's law. But, more important yet, the properties of space-time, as revealed by the study of accelerations, explain the curvature of worldlines, without resorting to mysterious attracting forces between distant bodies.

Worldlines curve for the same reason which causes a ball rolling on an uneven surface to change direction according to the inclinations of the surface. Four-dimensional space-time is grooved along the tracks of matter. This is what is meant by the statement that space-time is "non-euclidian." Masses must follow these grooves and the theory also shows that in doing so they fulfill the well-known principle in physics of *least action.*

Popular statements of the "relativity" law of gravitation generally introduce at this point the term "geodesic," *i.e.* the shortest route or interval length between two world-points. These geodesics are not straight lines in non-euclidian space-time and by stating that moving bodies follow geodesics the curvature of their path is supposedly explained. This is not strictly true. Let us take an example from our three-dimensional world, setting time aside for the present. If we are to move from New York to San Francisco the shortest route is through the earth, 2,555 miles long, and we would pass Omaha 204 miles below the earth's surface. If the earth were homogeneous, *i.e.* analogous to "euclidian" space, we would of course follow the straight line everywhere. But as we are apt to strike strata of different hardness, *i.e.* finding our space "non-euclidian," we might make better progress by dodging the hardest spots although thus lengthening our course. In that manner we might find many routes equally entitled to the claim of being the "shortest," *i.e.* to the name of "geodesic" and so we might hesitate which road to choose. But nature never hesitates; there is always some *unique* way of doing a thing and that way is always the choice of nature. With our "superior" intelligence we would prob-

ably suggest that the shortest line from New York to San Francisco is the geodesic of the surface of the earth which joins the two points and is 2,602 miles long; but the German cannon balls would never have reached Paris if they had shot through the air according to the rules of ordinary ballistics; it was only by searching the upper, rarefied layers of air, over a longer route, that the goal could be reached. To those cannon balls "air-space" was non-euclidian and the curvature of their path was governed by the law of "least action." And so in our four-dimensional world moving bodies find their "unique" path not along the shortest possible interval lengths but, peculiarly enough, "least action" is obtained along the *longest possible* interval lengths. (Our analogy is pictorial only and would be entirely misleading if rigorously applied.) Matter is building up space-time as various rocks and strata are building up the volume of the earth and as the various strata of air are building up the atmosphere, so that bodies moving in space-time follow curved paths as the worm in the earth, the road in the hills and the super-cannon ball in the air.

The network of worldlines is therefore distorted in the vicinity of matter. This property of space-time is difficult to conceive but no more so than the mysterious property of gravitational action on distance which the Newtonian theory asks us to believe in. The greater probability of the theory of relativity rests on the fact that it follows with mathematical necessity from the properties of space-time and the principle of equivalence and that its formulas give our present, less precise, laws, in a first approximation, and take care of their shortcomings in a second approximation. Like all theories it must be verified by experience and we have already seen that it accounts for many puzzles and anomalies of orthodox science. We shall now consider the most triumphal verification thereof. We have stated that space-time is grooved along the tracks of matter so that

other worldlines entering such regions must follow the grooves. This must apply to rays of light as well as to ponderable matter. Einstein therefore predicted that a ray of light coming from a distant star would be bent if grazing the disk of the sun on its way to an earthly observer. There is nothing substantial about light but because it exerts pressure on the surface it hits and because radioactivity early had shown that mass may exist by virtue of velocity alone, it was admitted that a ray of light might possibly bend in accordance with Newton's theory of gravitation when passing the sun. The theory of relativity, however, shows that there are two kinds of distortion in space-time around matter, one major, which in the main accounts for the Newtonian law of gravitation, and one minor, confined to space alone, which as a rule is insignificant even for stellar velocities. When we deal with the velocity of light, however, this second distortion rises to the same magnitude as the first and Einstein therefore predicted a deviation from a straight line just twice as large as could be expected if light, indeed, followed the Newtonian law. It is now a matter of common knowledge that the experiment was made during the last solar eclipse on May 29, 1919, and that even conservative scientists had to decide in favor of Einstein.

If therefore we are justified in believing in four-dimensional space-time, *almost* "flat" in *almost* empty regions, and curved where matter is present, we are able to draw a most inspiring picture of our universe. Who has not wondered what is "beyond the stars." If we consider a sufficiently large region of the universe we may say with fair accuracy that matter is on the whole uniformly scattered throughout the region. Each particle of matter contributes a small curvature to space-time so that a ray of light following the path of least resistance, *i.e.* the natural curvature, will be, not smoothly, but continuously bent. Ulti-

mately it must return to its source. The lightpulse will then have explored the entire space-time continuum and found that it is closed. It does not matter in which direction it starts out it always ultimately comes back again. It is therefore possible to explore every point of the universe and we must draw the conclusion that the universe is finite but on the other hand has no boundary. "Beyond the stars" simply does not exist. The difficulty we find in picturing such a universe to ourselves need not deter us from embracing the dogma for—is it easier to understand an infinite world? The best analogy found for closed space-time is the surface of a sphere. Flat beings confined to such a surface and unacquainted with the vertical so that they perceive length and width only must live in the faith of our own ancestors that their world is flat and must, like they, ponder whether it is infinite, whatever that may mean, or has boundaries, and in such case what there is in the great beyond. Imagine their bewilderment if it were proven that their world was finite and yet without boundaries. In whatever direction you started out you would eventually come back. In such a world every point is of equal importance and is a definite part of the whole in fact it is symmetrically placed with reference to the whole. So in our space-time every "event" marks in a sense a "central" point which cannot be disregarded by comparison to the infinite but is indeed an integral part of a definite scheme and interlaced through its worldline with every other part of the entire universe.

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